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6. AUTHOR(S) Robert T. M'Closkey and Greg P. Carman				
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13. ABSTRACT (Maximum 200 words) Our research objectives are to derive thermal and hysteresis models of actuation systems employing thin-film NiTi. Future actuators are likely to exploit the high energy densities available from NiTi, however, an impediment to its application in high-bandwidth actuators has been the slow thermal time constants associated with the bulk material. High-bandwidth actuators using thin-film NiTi show great promise due to the increased rates of heat transfer. This grant supported the design, fabrication, and characterization of a NiTi bubble actuator and the fabrication, testing, and excitation of a silicon beam's first resonant mode with a NiTi thin-film. This grant also supported the development of our thin-film processing techniques.				
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Final Progress Report

Control-Oriented Modeling and Feedback Compensation for a Thin-Film TiNi Actuator Robert T. M'Closkey and Greg Carman

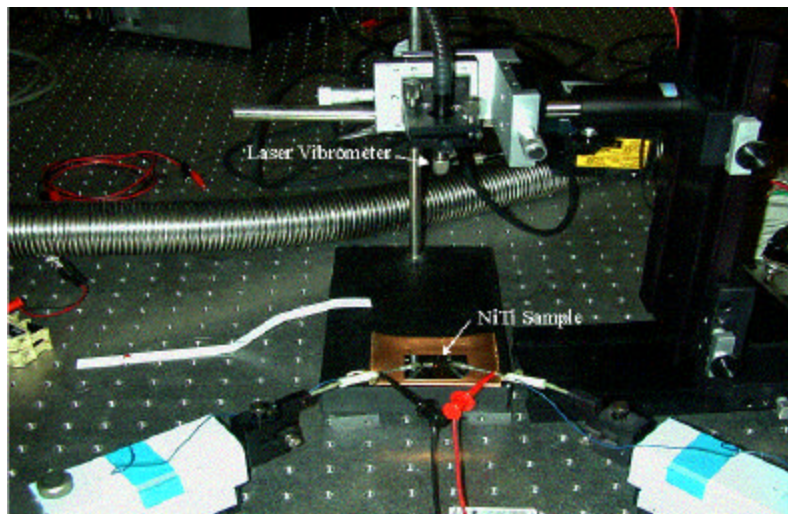
(1) Statement of problem studied.

Our research objectives are to derive thermal and hysteresis models of actuation systems employing thin film NiTi. Future actuators are likely to exploit the high energy densities available from NiTi, however, an impediment to its application in high-bandwidth actuators has been the slow thermal time constants associated with the bulk material. High-bandwidth actuators using thin film NiTi show great promise due to the increased rates of heat transfer. This grant supported the design, fabrication, and characterization of a NiTi bubble actuator and the fabrication, testing, and excitation of a silicon beam's first resonant mode with a NiTi thin film. This grant also supported the development of our thin film processing techniques.

(2) Summary of results.

Thermal model of a thin-film NiTi bubble actuator with different boundary conditions.

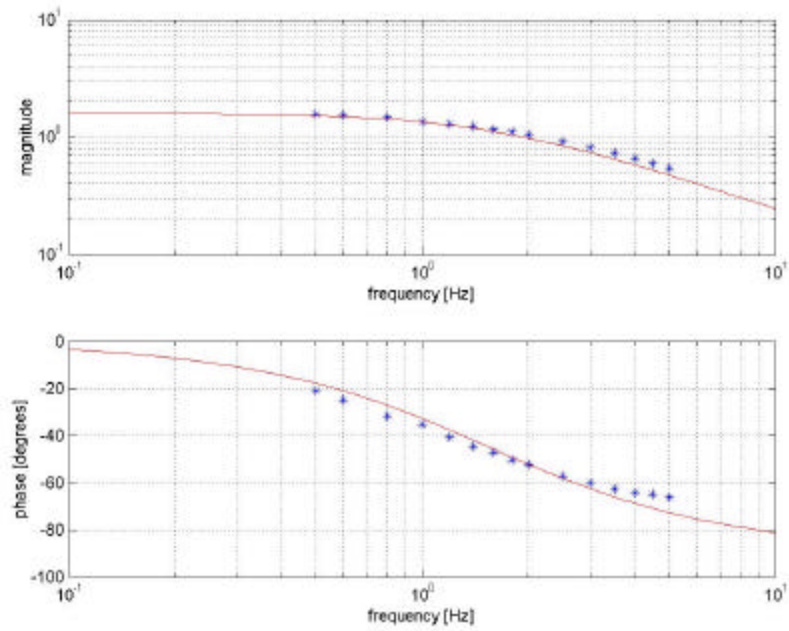
It is difficult to obtain direct dynamic measurements of the film temperature because thermocouple time constants are too slow, and also because large film deflections prevent adequate thermal contact between the film and thermocouple. We are able to infer temperature changes in the film, however, from coefficient of thermal expansion (CTE) effects. Thus, by measuring CTE-induced displacement, we can determine the thermal model to within a constant gain. This model has the form of a low pass filter (via an energy balance argument).



This test and measurement system is used to estimate the frequency response of the thermal block in the thin-film NiTi model: sinusoidal average power profiles of at a grid of frequencies are applied to the film and the sinusoidal responses from CTE effects are recorded. The magnitude and phase relationships of the power input and displacement are determined and summarized on frequency response plots. Different film boundary conditions are explored.

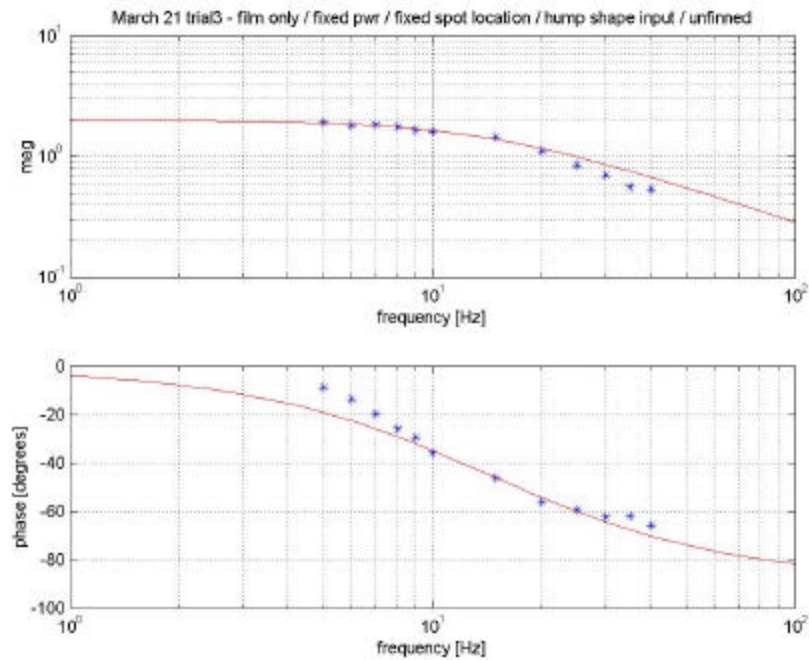
The frequency response results are presented below.

- a) Thin-film bubble actuator resting on a thin copper plate with no thermal grease:



The time constant is $t = 0.10$ seconds in a first-order thermal filter model.

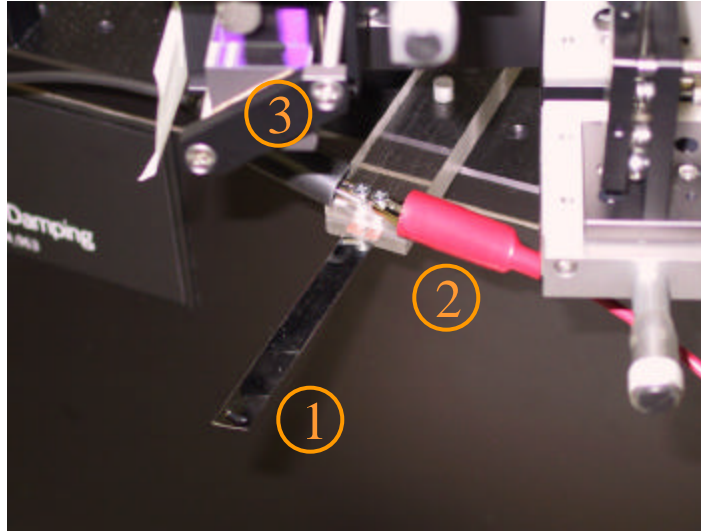
- b) Thin-film bubble actuator resting on a finned aluminum plate with thermally conducting grease:



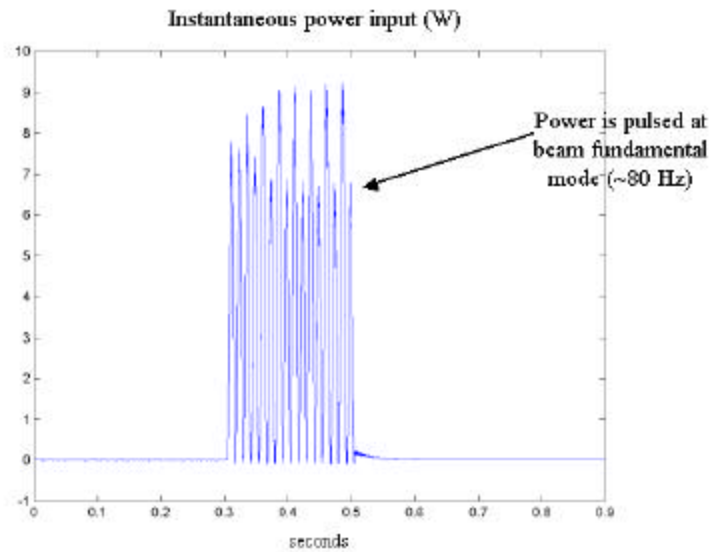
The time constant is $t = 0.011$ seconds in a first-order thermal filter model.

Excitation of resonant mode in silicon beam via NiTi thin-film .

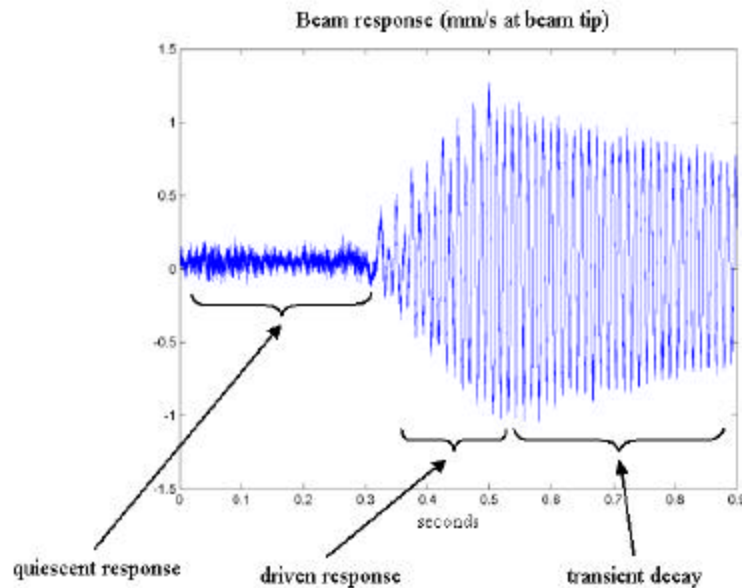
The figure below shows a silicon beam approximately 3 inches long, 0.4 inches wide, and 0.02 inches thick (designated “1” in the photo). One side of the beam has a layer of NiTi thin film. A vibrometer senses the velocity of a point in the beam surface (“3”) and power is supplied to the NiTi at “2”.



A 0.2 sec pulse at the beam’s first resonant mode (independently determined using a transient response test) is used to excite the NiTi. The NiTi input pulse is shown below.



The beam response is shown in the following figure. During the pulse, the beam’s amplitude grows in an almost linear manner. Our tests of a beam of similar dimensions and with superelastic NiTi thin-film is used a experimental control. The superelastic film does not undergo a phase transition (the transition temperature is below room temperature) and so its effects on the beam response are purely due to thermal expansion effects of the NiTi.



Our tests suggest that the beam response is due to the shape memory effect. Thus, it is possible to use thin-film NiTi as a high bandwidth actuator for disturbance attenuation or vibration suppression on elastic structures such as beams.

(3) List of publications.

a. Papers published in peer-reviewed journals:

1. Ho, K., Mohanchandra, K.P., Carman G.P. "Examination of Sputtering Profile of NiTi under Target Heating Conditions," *Thin Solid Film* (accepted).
2. Gill, J. and Carman G.P., "Three Dimensional Thin Film Shape Memory Microactuator with Inherent Two-Way Actuation," *J. Microelectromechanical Systems*, Feb 2002, Vol. 11, No. 1, pp. 68-78.

b. Conference proceedings:

1. Gill, J., Carman, G.P., and M'Closkey, R.T., "Evaluating the Properties of Thin Film NiTi Micro Actuators for Active Control," *Proc. Eighth Conf. Nonlinear Vibrations, Stability, and Dynamics of Structures*, July, 2000.
2. Mohanchandra, K.P.; Ho, K.K.; Carman, G.P. "Influence of target temperature on crystallization and properties of NiTi thin film shape memory alloy," *Proc. SPIE*, Vol.4333, 2001. p.426-32.

(4) Scientific personnel supported by this project.

Michael Yu, MS in Mechanical and Aerospace Engineering, UCLA, Summer 2000 –fully supported.

John Gill, PhD in Mechanical and Aerospace Engineering, UCLA, Fall 2000 –partially supported

Greg Carman, Professor, Mechanical and Aerospace Engineering.

Robert M'Closkey, Associate Professor, Mechanical and Aerospace Engineering.

(5) Inventions.

None.

(6) Bibliography.

None.

(7) Appendices.

Technology Transfer. We have transferred some of the thin-film technologies to a local company called Shape Change Technologies, LLD. They are developing applications in the biomedical and industrial markets including products such as pumps and optical membranes.

Awards. a) Best Paper Award, 2001 Adaptive Structures and Material System Committee ASME.
b) National Science Foundation CAREER Award, 2000 (M'Closkey).